UNCLASSIFIED

| AD NUMBER: AD0903645 |
|---|
| LIMITATION CHANGES |
| TO: Approved for public release; distribution is unlimited. |
| FROM: Distribution authorized to U.S. Gov't. agencies ; Test and Evaluation Use; 08 Aug 1972, other requests shall be referred to Naval Ship Systems Command, Washing, DC. |
| AUTHORITY |
| USNSRDC ltr dtd 2 Jan 1975 |

THIS PAGE IS UNCLASSIFIED

DEPARTMENT OF THE NAVY

NAVAL SHIP RESEARCH AND DEVELOPMENT CENTER

BETHESDA, MD. 20034

# THE EFFECT OF DECK DECELERATION ON THE RESPONSE OF SEATED MAN TO DECK MOTIONS INDUCED BY UNDERWATER EXPLOSIONS

by

C. E. Strother and R. M. Mahone



Distribution limited to U. S. Gov't agencies only;
Test and Evaluation Info. 8 Aug 1972
Other requests for this document must be referred
to NAVSHIPRANDCEN (Code 17)

August 1972

Report 3342

## TABLE OF CONTENTS



## LIST OF FIGURES

## ABSTRACT

The effect of the deceleration phase of deck response to underwater explosions on the response of seated man to such motions was investigated mathematically using a single-degree-of-freedom model to represent a man. It was concluded that the assumption of no deck deceleration does not result in significant errors for the majority of cases. However, deceleration is significant in situations where the duration of the positive acceleration is less than one-half the apparent natural period of seated man and the ratio of acceleration to deceleration is about 10 or less. Errors introduced by ignoring deceleration may lead to overestimates of casualties.

## ADMINISTRATIVE INFORMATION

This work was sponsored by the Naval Ship Systems Command (0342) Under Task Area 15796, SF 43.451.101

# INTRODUCTION

Underwater explosions produce violent, z-axis shock motions of ship decks. Man's response to these motions has been the subject of prior investigations at the Naval Ship Research and Development Center[1-3] Injurious levels of shock motions have been conservatively estimated by a semi-empirical technique[4] and used to derive a "sensitivity curve". As indicated by the example shown in Figure 1, the sensitivity curve expresses injury as a function of two shock parameters: applied acceleration and change in deck velocity.

To derive such a sensitivity curve, certain assumptions had to be made concerning both the shock input and man's response to that input. Shock input was modeled as a square acceleration pulse of a given duration; this will be considered further in a subsequent section of this report. Man was assumed to respond as a single-degree-of-freedom undamped linear spring mass system. Data on man's response to sinusoidal vibration were employed to provide an apparent natural frequency in the seated position. Since direct shock injuries are due to compressive forces acting on the body, injury was interpreted in the model as corresponding to a given amount of spring compression.

The above assumptions imply a definite relationship between the static compression of the spine required for fracture and the injurious

---

[1] References are listed on page 13

levels of shock motions. This relationship is shown in the sensitivity curve. Careful inspection of Figure 1 reveals that shock motions can be subdivided into two groups on the basis of their duration. For acceleration pulses that last longer than one-half of the apparent natural period of seated man, injury is sensitive to acceleration. The critical acceleration in such cases can be shown to be

$$A_{cr} = \frac{1}{2} \cdot X_c \cdot \omega^2 \qquad (1)$$

where $A_{cr}$ is the critical long-duration acceleration,

$X_c$ is the critical static compression, and

$\omega$ is the apparent natural frequency in radians/sec

For pulse durations that last less than one-half of the apparent natural period of seated man, injury is sensitive to the change in input velocity (i.e., acceleration times duration). The critical velocity change can be shown to be

$$\Delta V_{cr} = X_c \cdot \omega \qquad (2)$$

Reference 4 employed previously determined values of $X_c$ and $\omega$ to derive $A_{cr}$ and $\Delta V_{cr}$ using Equations (1) and (2). This resulted in a sensitivity curve for seated man such as that presented in Figure 1.

Figure 2 shows a typical deck motion-time history resulting from an underwater explosion. It is apparent that a period of approximately constant deceleration follows the positive acceleration phase of the

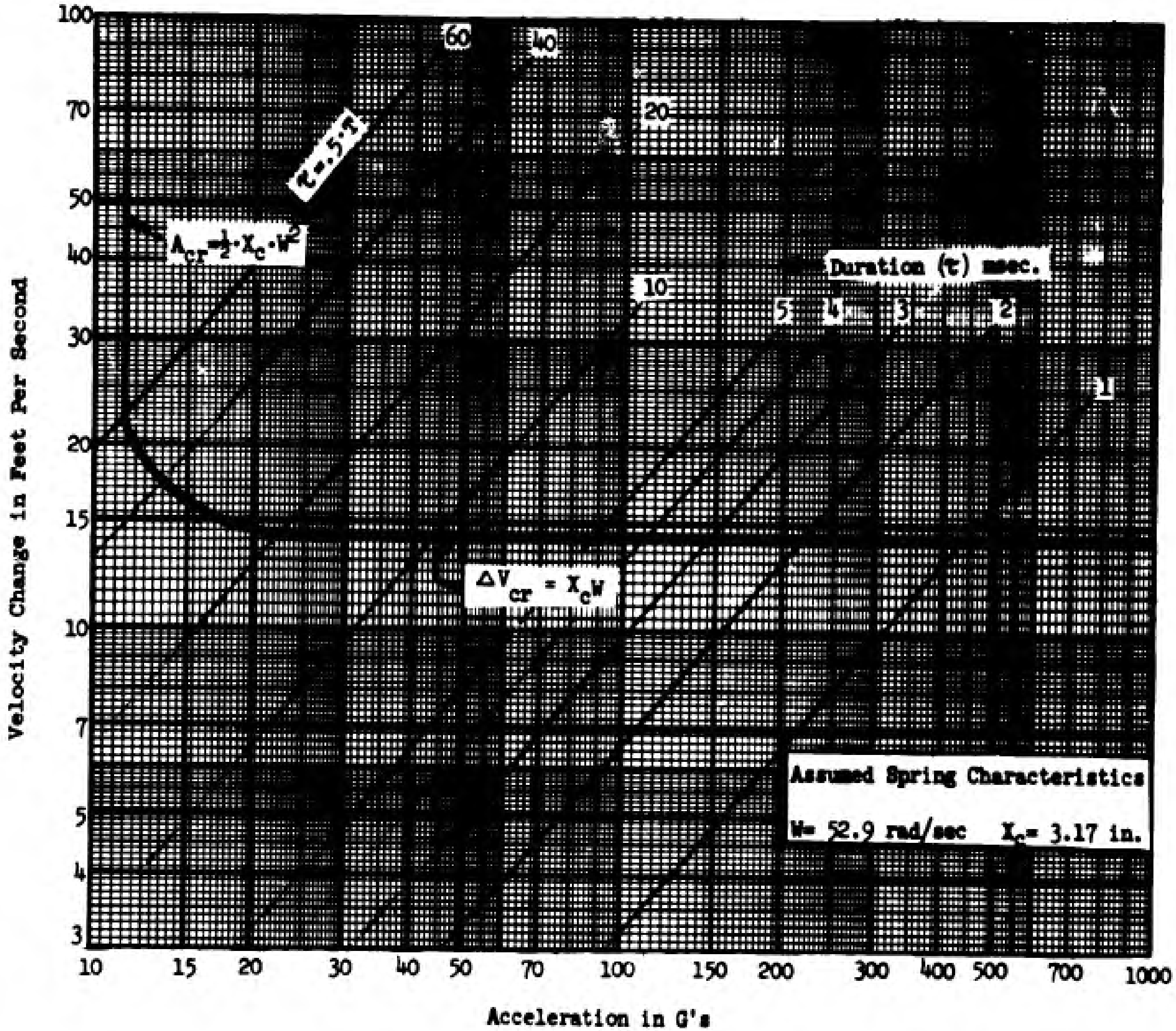


Figure 1 - Sensitivity Curve for Seated Man and No Deceleration

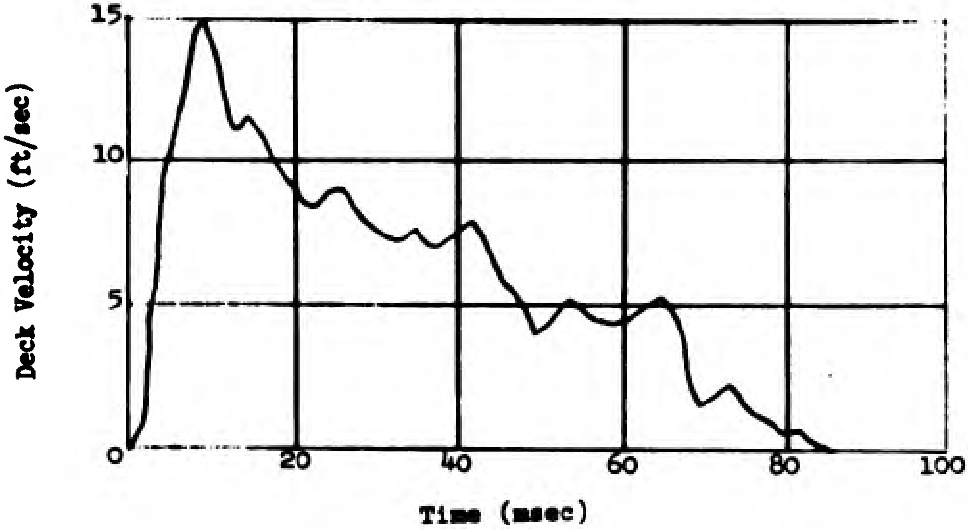


Figure 2 - Typical Deck Response to an Underwater Explosion

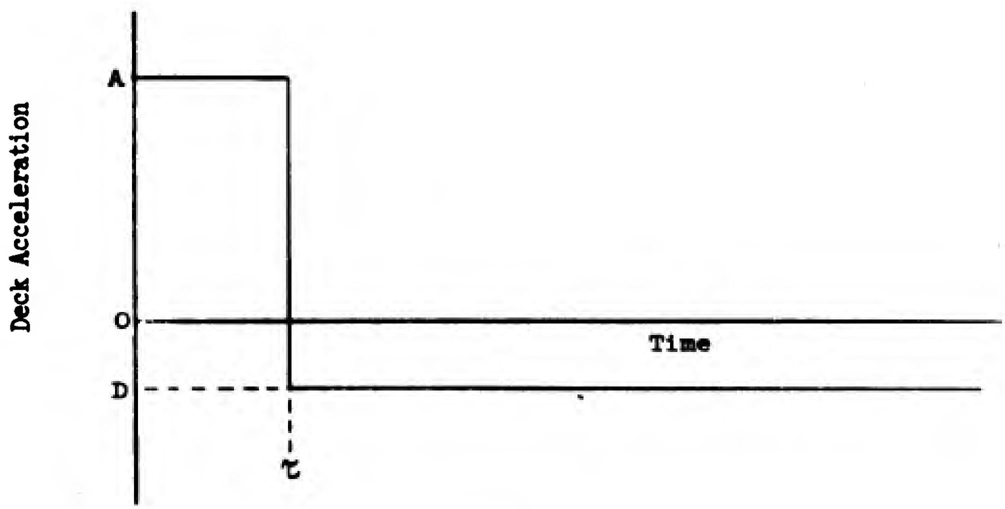


Figure 3 - Assumed Deck Motion

deck motion. Since in practical cases, the duration of positive acceleration $\tau$ is less than one-half the apparent natural period of seated man, the maximum compressive loading will occur during the deceleration phase of the deck motion. It should be evident then that man's response to shipboard shock motions will depend on the deck deceleration. It is the purpose of this report to determine the significance of this dependence.

## ANALYSIS

The input acceleration was assumed to be a two-phase acceleration history as shown in Figure 3. The duration of the positive acceleration was taken as less than one-half the apparent natural period of seated man. Seated man was represented in the mass-spring model by $\omega = 52.9$ rad/sec and $X_c = 3.17$ in. These values were from Reference 5 wherein $X_c = 3.17$ in. corresponds to the author's estimate of a 50-percent probability of injury (compressive fracture of the vertebra).

Maximum compression was found to occur at

$$t_{MAX} = \frac{1}{\omega} \cdot \mathrm{TAN}^{-1}\left[ \frac{(D+A)\cdot \mathrm{SIN}(\omega\tau)}{(D+A)\cdot \mathrm{COS}(\omega\tau) - A} \right] \qquad (3)$$

where

A and D are respectively the acceleration and deceleration (see Figure 3),

$\tau$ is the duration of positive acceleration A, and

The expression for the maximum compression is

$$X_{max} = \frac{A}{\omega^2}(1-\cos\omega t_{max}) - \left(\frac{A+D}{\omega^2}\right).(1-\cos\omega(t_{max}-\tau)) \quad (4)$$

## RESULTS

Figures 4, 5, and 6 are graphs of $X_{max}$ versus A for ratios of acceleration to deceleration (A/D) of 100, 10, and 1, respectively. Each curve on each figure represents a given value of the positive duration expressed nondimensionally as $\omega\tau/2\pi$.

Figures 4-6 were used to construct the sensitivity curve shown in Figure 7. Logically, as the A/D ratio increases, the sensitivity curve approaches that derived when deceleration is ignored ($A/D = \infty$) The significant result is that deceleration is an influential factor for A/D ratios of about 10 or less.

## DISCUSSION

The results showed that deceleration is a potentially important shock parameter in analyzing the response of seated man to shock motions. Ignoring deceleration may lead to errors which, fortunately, are on the safe side from a design viewpoint. For vulnerability assessments, however, ignoring deceleration may lead to overestimates of casualties. Deck decelerations sufficient in magnitude to result in A/D ratios of 10 or less can result from underwater explosions. Such situations

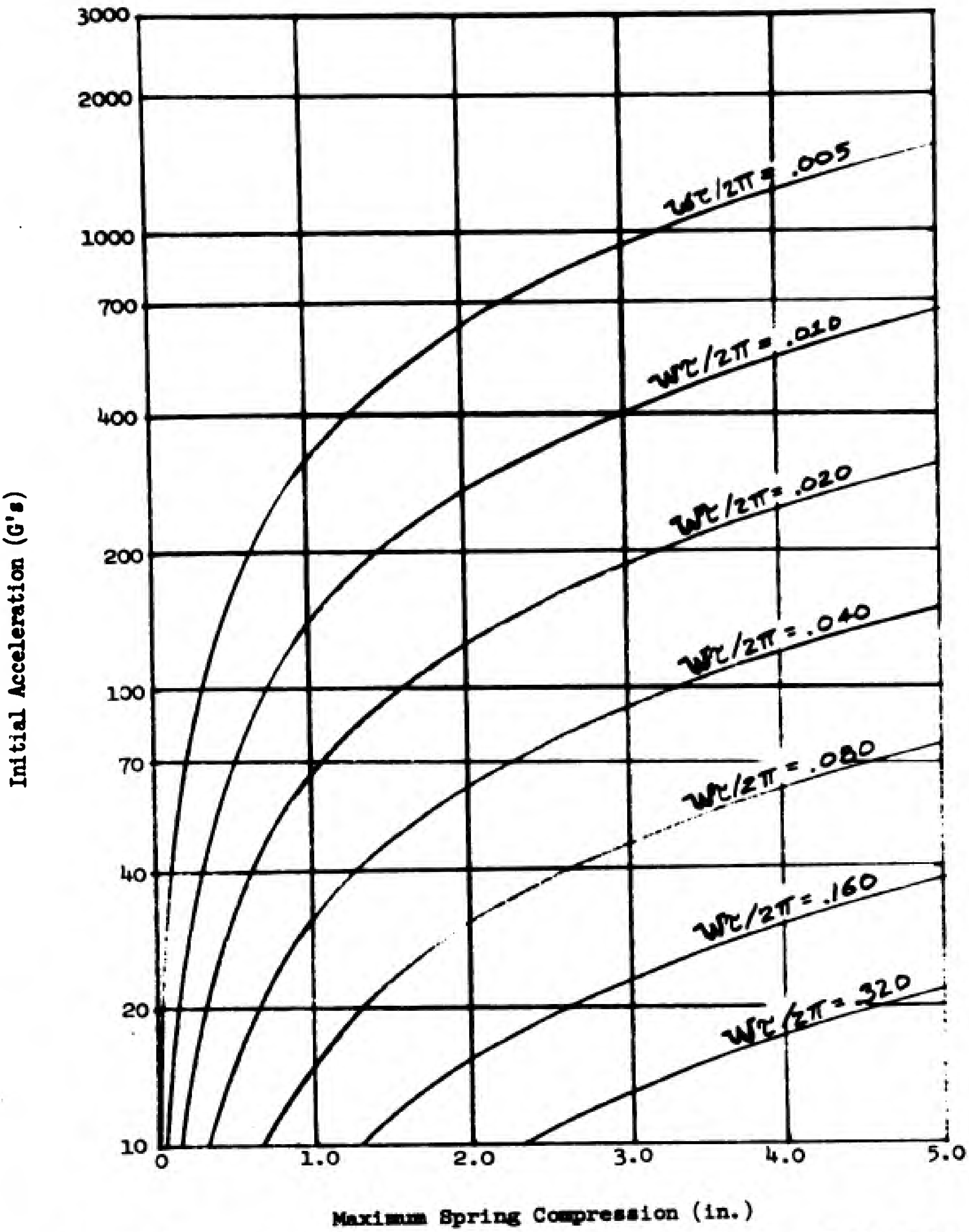


Figure 4 - The Maximum Spring Compression as a Function of the Initial Acceleration For the Case Where the Acceleration Equals 100 Times the Deceleration.

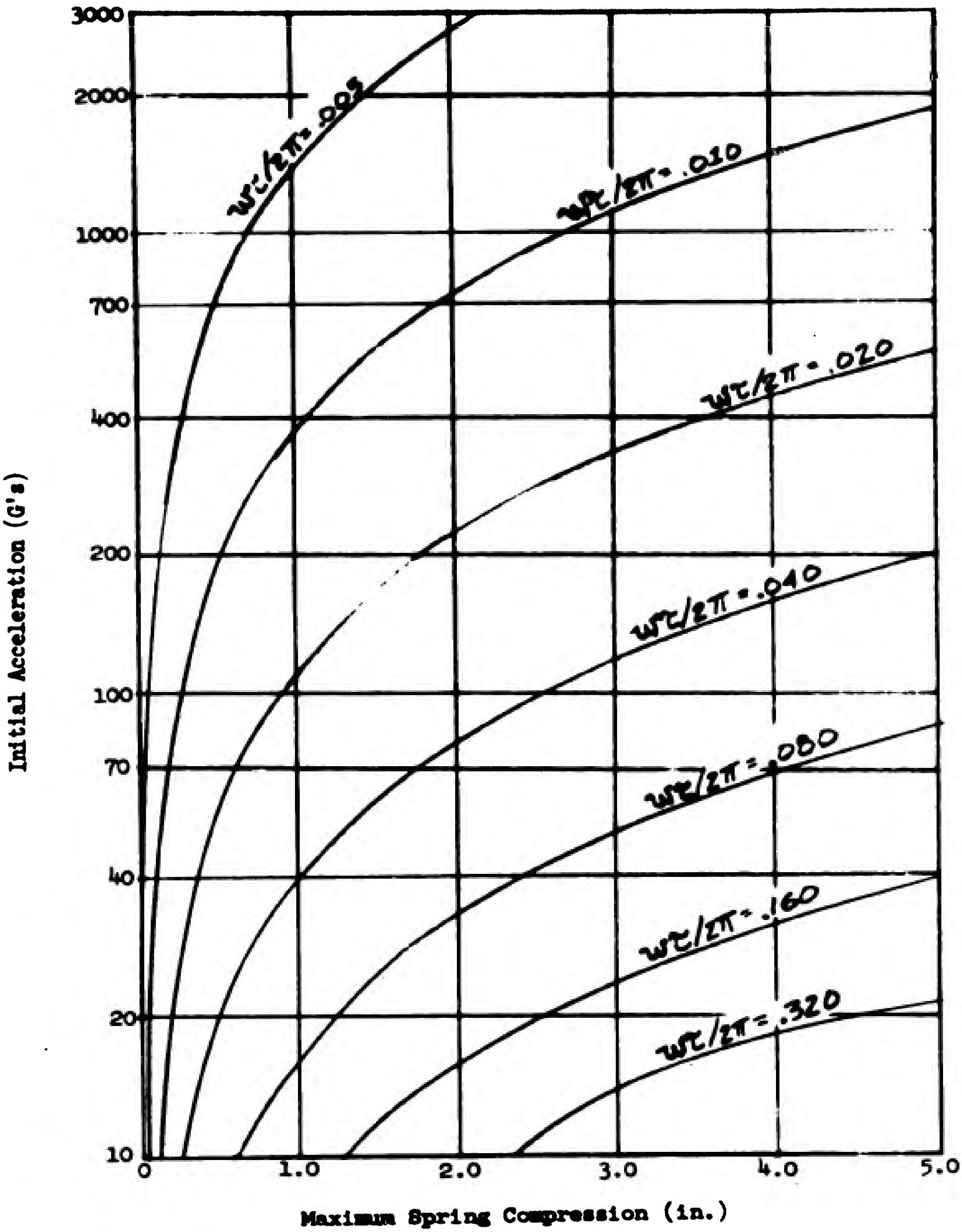


Figure 5 - The Maximum Spring Compression as a Function of the Initial Acceleration For the Case Where the Acceleration Equals 10 Times the Deceleration.

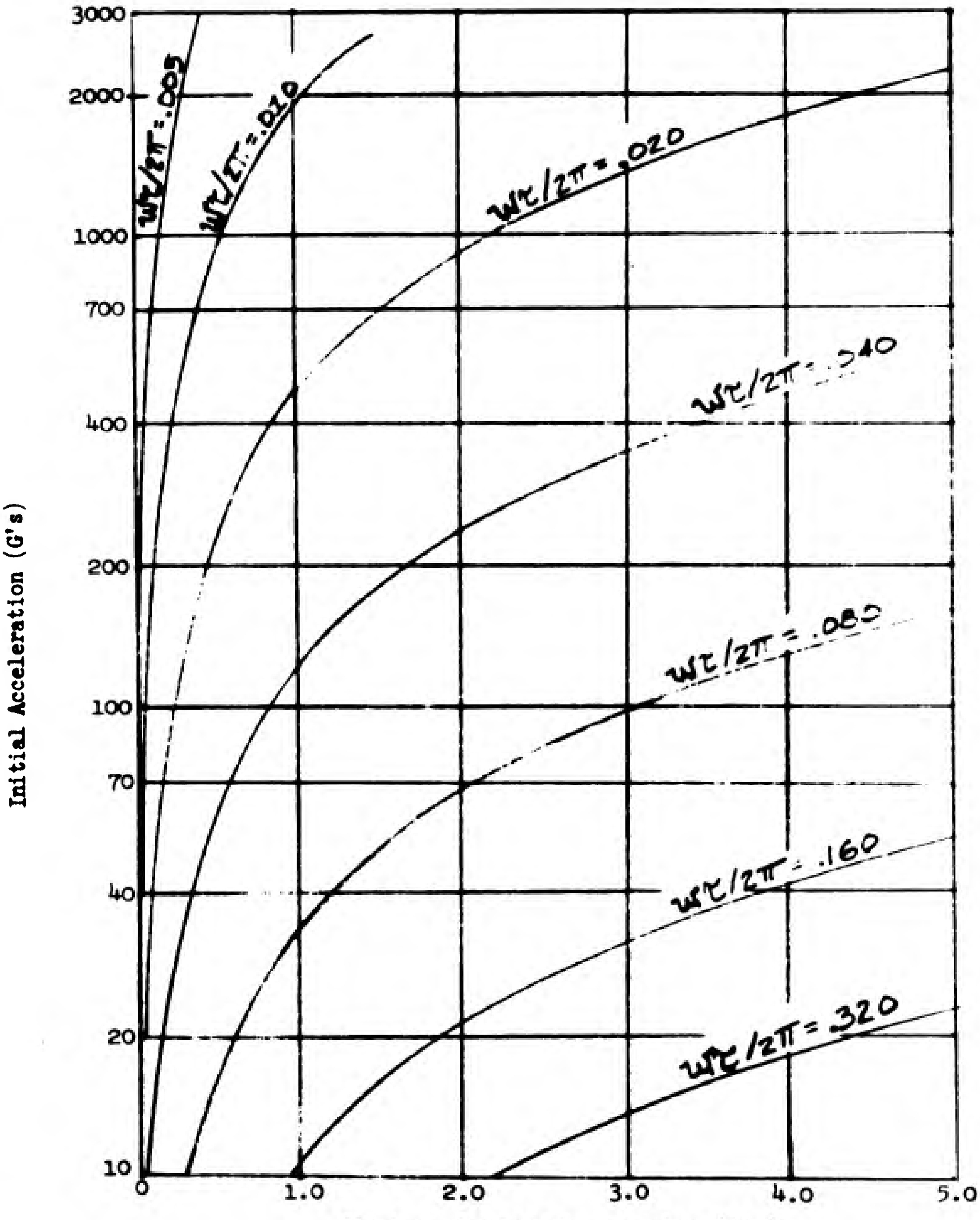


Figure 6 - The Maximum Spring Compression as a Function of the Initial Acceleration For the Case Where the Acceleration Equals the Deceleration.

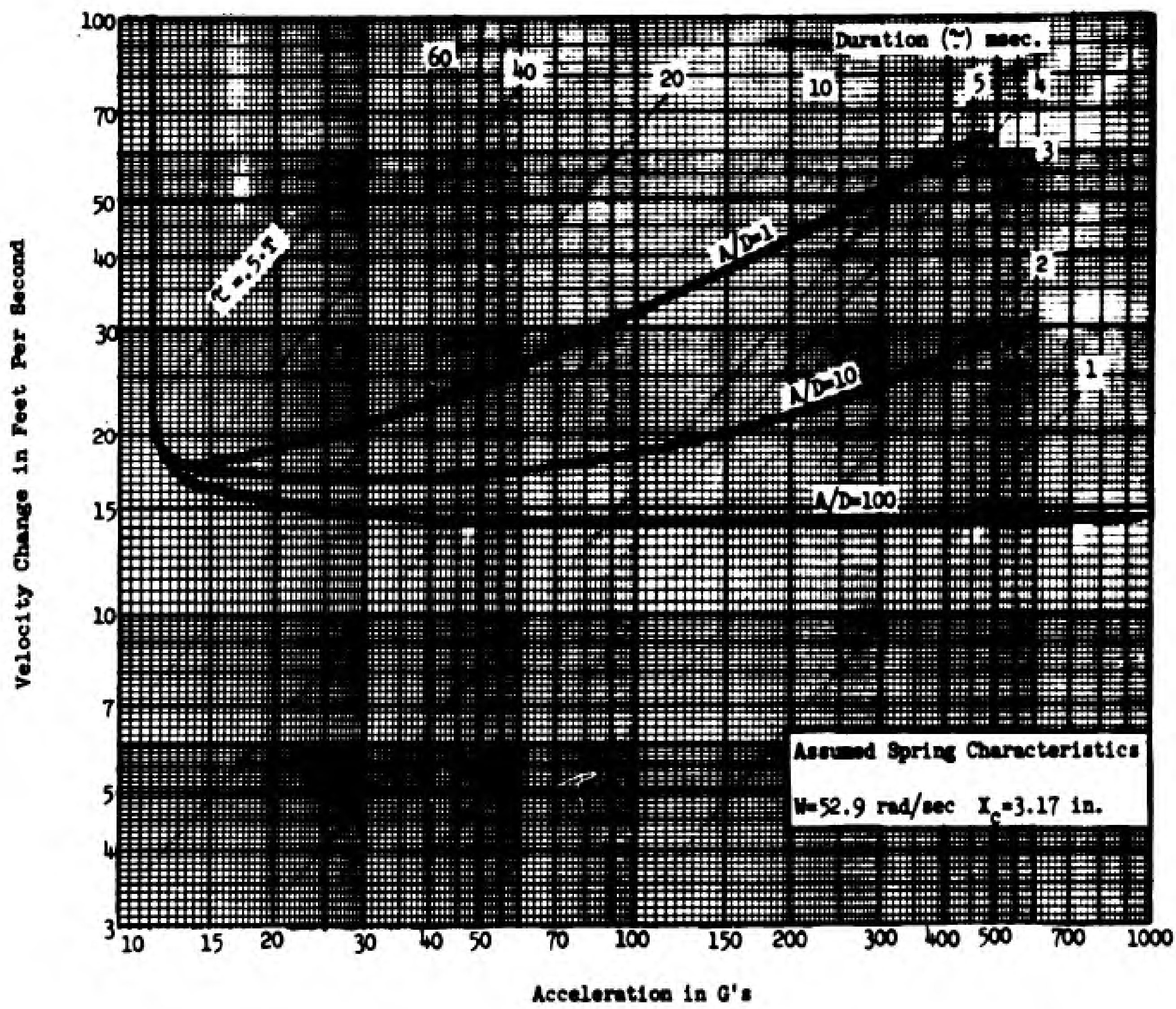


Figure 7 - Sensitivity Curve for Seated Man Assuming Ratios of Acceleration to Deceleration of 100, 10, and 1.

are the result of a shock-induced excitation in the first vibrational mode of a section of decking between stiffeners. In these cases, velocities are usually, but not always, below the range associated with direct injury (10-15 ft/sec). Examples of cases where high input velocities and decelerations occur in combination are available in Reference 6. It is clear that caution should be exercised in applying sensitivity curves that have been derived by ignoring deceleration.

Reference 7 contains velocity records obtained from the deck of an M551 tank exposed to detonations of shallow land mines. In many of these records, the A/D ratio is 10 or less and, hence, deceleration is a significant parameter. Other impact phenomena may also show characteristics which make deceleration important.

## CONCLUSIONS

Under the assumptions set forth in this report it is concluded that:

1. Man's response to vertical shock accelerations in the seated position will depend on the applied deceleration (a) if the duration of the positive acceleration is less than one-half the apparent natural period ( $\sim$59.3 msec) of seated man and (b) if the ratio of acceleration to deceleration (A/D) is about 10 or less.

2. The exclusion of deceleration may introduce significant errors in the analysis of seated man's response to vertical deck shock motions induced by underwater attack. These errors will be on the conservative side from a design viewpoint. For vulnerability assessments, however, ignoring deceleration will, in many cases lead to overestimates of casualties.

## REFERENCES


1. Hirsch, A.E.,"Man's Response to Shock Motions," David Taylor Model Basin Report 1797 (Jan 1964).

2. Hirsch, A.E. and Johnson, B.,"Personnel Casualties Resulting from Underwater Explosive Attacks against Naval Surface Ships (U)," David Taylor Model Basin Report C-1582 (Aug 1963) CONFIDENTIAL.

3. Hirsch, A.E., "Effects of Underwater Shock on Personnel (U)" Sec. 5.2 of Chapter 5, Part II of "Handbook of Underwater Nuclear Explosions," DASA-1240 11 (5.2), David Taylor Model Basin Report C-1871 (Aug 1965) CONFIDENTIAL.

4. Kornhauser, M., "Structural Effects of Impact," Cleaver-Hume Press, London (1964).

5. Brinkley, J.W. et al., "Evaluation of the Effects of Selected Egress System Design Parameters during $+G_z$ Acceleration," paper presented at the Aero Space Medical Conference, San Francisco (5-8 May 1969).

6. Strother, C.E.,"An Evaluation of the Threat to Personnel Aboard an Assault Patrol Boat (ASPB) Exposed to an Underwater Explosion (U)," encl (1) to NSRDC ltr Ser 69-740-1250 of 18 Jun 1969, CONFIDENTIAL.

7. Strother, C.E., "Estimated Probability of Direct Shock Injuries Among the Crew of a M551 Vehicle as a Result of Shock Motions Produced by Detonations of M-15 Land Mines (U)," encl (1) to NSRDC ltr Ser 01075 of 30 Dec 1969, CONFIDENTIAL.

Distribution
Not Shot

UNCLASSIFIED

Security Classification

**DOCUMENT CONTROL DATA - R & D**

(Security classification of title, body of abstract and indexing annotation must be entered when the overall report is classified)

1. ORIGINATING ACTIVITY (Corporate author)

NAVAL SHIP RESEARCH AND DEVELOPMENT CENTER
Bethesda, Maryland 20034

2a. REPORT SECURITY CLASSIFICATION

UNCLASSIFIED

2b. GROUP

3. REPORT TITLE

THE EFFECT OF DECK DECELERATION ON THE RESPONSE OF SEATED MAN TO DECK MOTIONS INDUCED BY UNDERWATER EXPLOSIONS

4. DESCRIPTIVE NOTES (Type of report and inclusive dates)

Research and Development Report

5. AUTHOR(S) (First name, middle initial, last name)

Charles E. Strother and Richard M. Mahone

| 6. REPORT DATE | 7a. TOTAL NO. OF PAGES | 7b. NO. OF REFS |
|---|---|---|
| August 1972 | 17 | 7 |

| 8a. CONTRACT OR GRANT NO. | 9a. ORIGINATOR'S REPORT NUMBER(S) |
|---|---|
| b. PROJECT NO. SF 451 101 Task 15796 | 3342 |
| c. | 9b. OTHER REPORT NO(S) (Any other numbers that may be assigned this report) |
| d. | |

10. DISTRIBUTION STATEMENT

Distribution limited to U. S. Government agencies only;
Test and Evaluation Info. 8 Aug 1972
Other requests for this document must be referred to NAVSHIPRANDCEN (Code 17)

| 11. SUPPLEMENTARY NOTES | 12. SPONSORING MILITARY ACTIVITY |
|---|---|
| | Naval Ship Systems Command<br>Code 03423<br>Washington, D.C. |

13. ABSTRACT

The effect of the deceleration phase of deck response to underwater explosions on the response of seated man to such motions was investigated mathematically using a single-degree-of-freedom model to represent a man. It was concluded that the assumption of no deck deceleration does not result in significant errors for the majority of cases. However, deceleration is significant in situations where the duration of the positive acceleration is less than one-half the apparent natural period of seated man and the ratio of acceleration to deceleration is about 10 or less. Errors introduced by ignoring deceleration may lead to overestimates of casualties.

DD FORM 1 NOV 65 1473 (PAGE 1)

S/N 0101-807-6801

UNCLASSIFIED

Security Classification

| 14. KEY WORDS | LINK A ROLE | LINK A WT | LINK B ROLE | LINK B WT | LINK C ROLE | LINK C WT |
|---|---|---|---|---|---|---|
| Shock Motions | | | | | | |
| Man's Response | | | | | | |
| Impact Loading | | | | | | |
| Personnel Protection | | | | | | |